Recommendation ITU-R S.1503 PFD Mask Generator Tool

Abstract: Non-GSO satellite networks wishing to operate in parts of C, Ku and Ka band must meet interference thresholds in the Radio Regulations defined using the Equivalent Power Flux Density (EPFD) metric. The EPFD is calculated using the methodology in Recommendation ITU-R S.1503 and then compared against the limits in Article 22. One of the key inputs to this methodology is the non-GSO satellite's PFD mask, which defines the maximum power flux density (PFD) that each satellite will emit at any moment during the lifetime of the constellation. It is important to ensure that PFD masks are defined in a way that is consistent with the non-GSO constellation to ensure that the system can achieve a favourable finding during the examination while operating at maximum feasible capacity. This Technical Note (TN) describes how to derive PFD masks using the PFD Mask Generator Tool. An iterative approach allows for the highest possible PFD mask whilst satisfying S.1503 EPFD verification.

What is EPFD?

EPFD stands for the Equivalent Power Flux Density and is defined in Article 22.5C.1 of the Radio Regulations. At first sight this equation looks daunting, but at its core it is relatively straight-forward and builds on the concept of the power flux density or PFD.

The PFD can be calculated from a transmitter's EIRP as follows:

$$PFD = \frac{EIRP(\theta)}{4\pi d^2}$$

It can be seen to represent the power density of the radio signal as it passes through a square unit of distance (typically metres) at a distance *d* from the transmitter. As the EIRP could vary depending upon the direction (for example if the transmitter didn't use an isotropic antenna), the term depends upon angle, here identified using θ.

The idea of the EPFD is that in many cases the victim receiver has a directional antenna and so the impact of PFD on its performance will depend upon the relative gain towards the interfering station.

Hence:

$$EPFD = PFD.G_{r,rel}(\varphi) = \frac{EIRP(\theta)}{4\pi d^2}G_{r,rel}(\varphi),$$

where the EIRP in Watts is calculated from the transmit power P in dBW and transmit gain as follows:

$$EIRP(\theta) = 10^{\frac{P}{10}}.G_t(\theta)$$

and the relative receive gain is the ratio of the receive gain in the required direction to the peak receive gain:

$$G_{r,rel}(\varphi) = \frac{G_r(\varphi)}{G_{r,max}}.$$

The final stage is to note that the EPFD is an aggregate term and so must be summed over all contributing transmitting stations.

The result is the equation that defines EPFD in Article 22.5C.1 of the Radio Regulations:

$$EPFD = 10\log_{10}\left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}}.\frac{G_t(\theta_i)}{4\pi d_i^2}.\frac{G_r(\varphi_i)}{G_{r,max}}\right]$$

Note that this is, in effect, a measure of the level of interference at the victim receiver.

It should be noted that there are different types of EPFD. For example, there are a number of different interference paths that need to be considered:

- EPFD(down): interference from the non-GSO satellite's downlink into the GSO system's downlink

- EPFD(up): interference from the non-GSO satellite's uplink into the GSO system's uplink

- EPFD(is): intersatellite interference from the non-GSO satellite's downlink into the GSO system's uplink

This TN only considers the EPFD(down) case.

Calculating EPFD using Recommendation ITU-R S.1503

Article 22 of the Radio Regulations defines hard limits that non-GSO FSS networks must meet – and which the ITU Radiocommunication's Bureau (BR) must check – but how are they to do that?

The answer is the algorithm specified by Recommendation ITU-R S.1503: *Functional description to be used in developing software tools for determining conformity of non-geostationary-satellite orbit fixed-satellite system networks with limits contained in Article 22 of the Radio Regulations.*

This document, mostly written by Transfinite consultants, defines how to calculate the EPFD levels that would be generated by a non-GSO network given parameters filled with the BR according to Appendix 4.

A key input is the power emitted by the non-GSO satellite, which for the EPFD(down) case is via a satellite emission PFD mask. This defines the PFD on the surface of the Earth that should never be exceeded. This PFD could in theory be measured to check that the levels filed have not been exceeded.

The reason for using masks is that it permits the non-GSO to change their operational systems as long as they do not exceed the mask filed with the BR.

Use of the PFD mask for EPFD(down) simplifies the EPFD calculation to:

$$EPFD = PFD.G_{r,rel}(\varphi)$$

This PFD mask can be defined in a number of ways, including varying by:

- α = alpha angle and difference in longitude
- X angle and difference in longitude
- Azimuth and elevation at the non-GSO satellite

The α angle is a key concept in Rec. S.1503 and it is defined as the minimum angle between:

- The line from the GSO ES to the non-GSO satellite
- The line from the GSO ES and any test point on the visible GSO arc

The X angle is similar but defined at the non-GSO satellite.

Note that the (azimuth, elevation) coordinate frame is defined in Recommendation ITU-R S.1503 as being north orientated.

The PFD mask can also vary by latitude and, if necessary, by satellite. However, it is not dependent upon longitude (or ITU Region), as so the PFD value at a particular latitude should be maximum for all longitudes at that latitude.

So, if the PFD mask is the key input for the EPFD(down) verification process, how can it be specified – and checked?

Generating a PFD Mask

The PFD mask should define the highest level of emissions that a non-GSO satellite will transmit at over each satellite's life-time. The idea is that it could be measured by any concerned party to ensure that the system is operating within its filed parameters.

The PFD should therefore be calculated as the maximum possible power over all potential traffic conditions over all longitudes. The calculation should take account of details of the non-GSO system such as:

- Non-GSO satellite height
- Non-GSO satellite number of antennas and beams

- Antenna / beam peak gain and beamwidth
- Antenna / beam gain patterns
- Antenna / beam pointing methods (fixed, tracking etc.)
- Carrier frequency(s) and frequency re-use
- Carrier bandwidths
- Carrier powers
- Traffic levels
- Tracking strategy (often using ε_0 = minimum elevation angle and α_0 = GSO arc avoidance angle).

These types of parameter can be modelled in a Visualyse Professional simulation. Creating a simulation with all these parameters allows the PFD to be calculated at a test point on the Earth's surface.

The PFD can be calculated at a wide range of points using the Area Analysis (AA) feature. Additional AAs can also be used to calculate the following parameters:

- Azimuth at satellite
- Elevation at satellite
- Alpha angle at satellite

Hence with a set of overlapping AAs it is possible to calculate the PFD and associated parameters for the PFD mask. By repeating the process at different latitudes and post-processing the resulting data it is possible to generate a complete PFD mask.

If the satellite system uses fixed beam pointing, then the PFD can be calculated from the maximum power directly. However, if the system uses steerable spot beams, then the PFD will depend upon the pointing angles at each moment in time. The PFD mask is the maximum over all possible combinations, hence it is necessary to undertake a Monte Carlo analysis, varying the beam pointing over many different combinations until there is confidence that the resulting PFD is the maximum possible.

This approach is described in more detail in a separate Technical Note.

PFD Mask Generator Tool

The PFD Mask Generator Tool is an add-on to the Visualyse EPFD product. It can be used to generate PFD Masks to meet the requirement of Recommendation ITU-R S.1503.

There are a number of different link design and antenna pointing options that can be used by non-GSO satellite systems, including:

1. Steerable spot beams, either physically pointed or using electronic steering

2. Fixed beam pattern of beams, which might be tilted and/or switched off depending upon geometry

3. Single fixed beam which is either on or off, such as an isotropic, omni or isoflux antenna used for TT&C.

This tool can be used to model systems with options 1. or 3. Satellite systems with a fixed pattern of beams can best be modelled using Visualyse Professional.

User Interface

The tool is managed via a dialog as shown below:

Note that software features and the user interface are regularly updated though a continuous process of development.

The user interface can be used to define aspects of the PFD Mask generation process, as described below.

PFD Mask Header

The first part of the dialog allows the PFD mask header to be defined, including the:

- Satellite name
- Notice ID
- PFD Mask ID
- EIRP Mask ID (if required)
- Minimum and maximum frequency.

Non-GSO Satellite System

The next section allows definition of key aspects of the non-GSO satellite system's design, including:

- Height
- Minimum elevation angle
- Minimum angle to the GSO arc
- Whether the antenna is fixed pointing or steerable
- Whether the system is only switched on for specific latitudes and if so what latitude.

EIRP and Gain Patterns

The main section defines the satellite emissions and how the PFD varies. This depends upon whether the antenna is fixed or steerable.

For fixed antenna patterns the key factors are the:

- EIRP
- gain pattern
- pointing (azimuth, elevation).

For steerable systems the calculations are more complicated and can include factors such as:
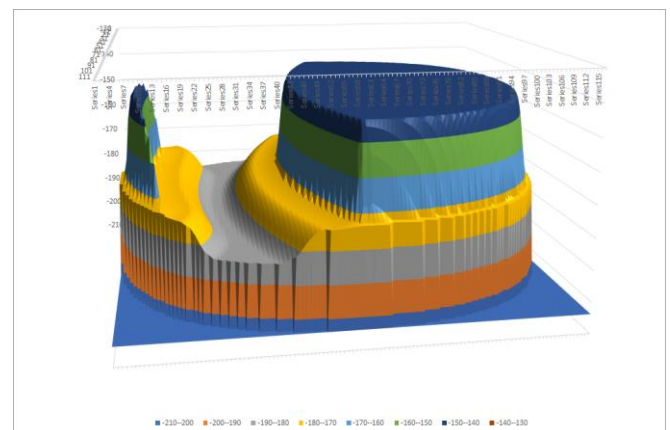
- EIRP
- Whether power control is used
- Antenna roll-off
- Whether additional control is used to manage the in-line geometry PFD
- Whether additional control is used to manage the FSS and BSS gain patterns far-off-axis notch.

Average Distance

An option allows the average distance to be calculated based upon the parameters entered for the steerable system. A factor can be used to tune this to take account of the likelihood that the satellite used to provide a service will more likely be the one at the highest elevation.

Output

This section defines what should be outputted and what grid to use for the PFD(az, el) format. Options allow additional tables to be created which show slices of the PFD mask at each latitude. This can be used to visualise and check the PFD table, as in the example below:

It is also possible to use the parameters entered to create a satellite EIRP mask.

Version Control

The parameters used can be saved to a text file and used again. This ensures that there is traceability and repeatability of the PFD mask generation process.

Use of PFD Masks in Analysis

Having created the PFD(az, el) or PFD(α) table at one latitude it would be necessary to repeat the process to create a full PFD mask. This could then be saved in XML format for use within the EPFD verification process.

The result of running the EPFD verification software with a PFD mask is either a pass or fail. This can lead to further questions:

- If the result was pass: which parts of the PFD mask could be *increased* and by how much?

- If the result was fail: which part of the PFD mask should be *decreased* and by how much?

These questions can be answered by combining the PFD Mask Generator tool with Visualyse EPFD: the latter gives information about how and why the EPFD limits were exceeded while the former allows the PFD mask generation process to be updated accordingly.

An iterative process can be used that results in the highest PFD mask (which therefore provides the maximum flexibility in operation) with a successful pass of the S.1503 EPFD verification process.

Conclusions

This TN has shown how to use the PFD Mask Generator tool to create PFD masks required for S.1503 analysis.

How we can help

We are world experts on EPFD and the verification of non-GSO networks against the limits in Article 22 of the Radio Regulations. As well as the software products Visualyse EPFD, Visualyse Professional, Visualyse Coordinate and Visualyse GSO we can provide training services.

Visualyse EPFD

Our Visualyse EPFD software is the leading implementation of the algorithm in Rec. ITU-R S.1503. It has been verified during testing with the ITU BR and can calculate EPFD(up), EPFD(down) and EPFD(IS).

It can also analyse both the Article 22 and Articles 9.7A and 9.7B cases. It is available in two versions, one the ITU's "black-box" for pass/fail decisions and the other a product with graphical user interface that provides feedback on the calculation process and allows additional options to be modified.
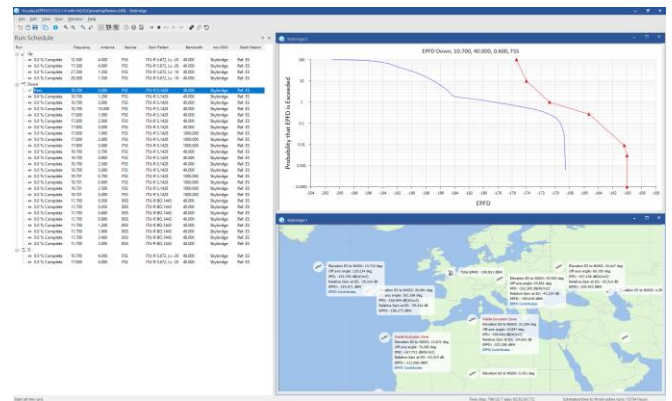

Visualyse Professional

Our desktop study tool Visualyse Professional can be used to analyse radio systems including both GSO and non-GSO networks.

Unlike Visualyse EPFD which uses the PFD mask approach in Rec. S.1503, Visualyse Professional calculates EPFD using a full simulation approach that models each beam and the tracking strategies involved.

This can model actual operation and includes all three EPFD cases of up, down and intersatellite. It could, for example, be used during the coordination triggered by Article 9.7A and 9.7B of the RR.

Visualyse Professional could also be used in coordination between non-GSO networks.
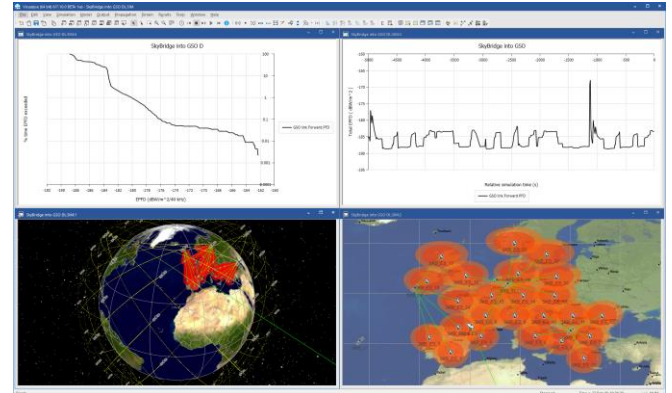
Visualyse GSO

We have developed Visualyse GSO to support satellite coordination tasks, in particular for GSO satellites. It includes IFIC checking, detailed C/I calculations and integrates with ITU databases such as the SRS/IFIC and GIMS. It can be also used to identify coordination requirements of non-GSO satellites.

Contact us

If you have any questions or comments about this Technical Note or would like more information, please do not hesitate to contact us at:

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